Effect of introducing *Allolobophora longa* Ude on root distribution and some soil properties in New Zealand pastures

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SUMMARY

1 In some New Zealand pastures, poor soil structure appears to reduce pasture production through adverse soil moisture conditions and restriction of plant roots.
2 Many soils contain only the earthworm species *Allolobophora caliginosa* and *Lumbricus rubellus* with a major zone of activity within the top 10 cm of soil.
3 Introducing a deeper burrowing species, *A. longa*, to limed soil, increased surface infiltration rates, total soil porosity at 10–20 cm, and root biomass at 15–20 cm. Pasture growth was also increased in some seasons.
4 These changes were associated with increased surface casting by *A. longa* and greater mixing of surface applied lime throughout the soil profile.

INTRODUCTION

On some sheep-grazed hill country in the East Coast of the North Island of New Zealand, pasture growth may be limited by factors related to soil structure. Soils may become very wet in winter with consequent low oxygen diffusion rates below 5–7 cm in the soil profile. Downward penetration of roots, particularly of clover is restricted. In winter, roots are seen to rot off at a depth of about 7 cm. In summer, the same soils dry out very rapidly, subjecting the shallow rooted pasture to sudden severe water stress.

These soils typically have substantial populations of *Allolobophora caliginosa* (Sav.), *A. trapezoides* (Duges) and *Lumbricus rubellus* Hoff. The top 5–7 cm of soil is well structured with no turf mat development at the surface. Penetration of worms below this level is limited to relatively few burrows formed in late spring as the worms move downwards to depths of 15–25 cm to aestivate.

This situation is typical of many New Zealand pastures which have been developed out of native bush. The indigenous earthworm fauna comprises five to nine species including litter-dwellers, top soil mixers and subsoil species (Lee 1959). When the native vegetation is cleared and grasses sown, the indigenous fauna disappears, although in some cases the subsoil species may survive for many years. Following clearing, there is a period during which the soil is exposed to direct impact by rainfall, trampling by stock, and much larger diurnal climatic variations than occurred under a tree canopy. In time, an earthworm fauna comprising a small number of accidentally introduced European species becomes established.

The changes in soil properties which occur when the native vegetation is converted to improved pasture have been reported (Stockdill & Cossens 1966). This paper reports on the changes in soil properties following the introduction of a deeper burrowing species, *A. longa* Ude., into pasture soils already colonized by *A. caliginosa*, *A. trapezoides* and *L. rubellus*.

MATERIALS AND METHODS

Study area

The trial site was situated on a sheep farm on the East Coast of the southern North Island at Porongahau. The pasture was predominantly perennial ryegrass (*Lolium perenne* L). and white clover (*Trifolium repens* L) which was rotary cultivated and resown 3 years before the first earthworm introduction. The soil was a yellow grey earth (During 1972) with a pH of 5·5. The area was grazed by sheep on a set stocked/shuffle system at 12 stock units* ha^{-1}. The climate is temperate to Mediterranean in type with moist cool winters and warm dry summers. The dry season usually lasts from December until March but there may be extended droughts or heavy summer rains.

Methods

Two separate trials were set up on the same farm in consecutive years. In the first trial, *A. longa* were introduced to plots treated with 5000 kg ha^{-1} of lime; and other limed and unlimed plots were left free of earthworms. Each of the three treatments was replicated six times. The plots were small (1 m^2) and were used mainly for dry matter production measurements. Lime and earthworms were added on the same day. In the second year, larger plots (2 × 2 m) were set up with only two treatments, added *A. longa* and a control without *A. longa*, to enable destructive soil samples to be taken. Both treatments were replicated six times.

Earthworm introduction took place in August of each year. *A. longa* were collected by digging and hand-sorting from pastures known to have high populations of this species. The worms were matched for size and proportion of mature worms and were placed on the surface of the plots at a rate of 150 m^{-2}. Any worms which had not burrowed into the soil within 30 minutes were replaced. The plots were protected against birds until all worms had disappeared from the soil surface. The first trial was fenced to prevent grazing, the second trial was open. Measurements on pasture and soil properties were made over an 18 month period after earthworm introduction.

*A stock unit is equivalent to a 55 kg live weight Romney ewe producing 1 lamb per year and consuming 550 kg dry matter per year.

Trial 1

Pasture production was estimated by occasional cuts in October and November 1981, and April, September and October 1982. The herbage was trimmed to a height of 3 cm and subsequent growth after 3–4 weeks was measured by cutting the entire plot to a height of 3 cm. The harvested pasture on the different treatments was compared at each date of cutting.

Soil pH (2·5:1 in water) was measured after cutting soil cores into 2 cm horizons, 9 months after lime and worms had been spread.

Trial 2

Root biomass was measured in fifty cores 10 cm^2 in surface area and 20 cm deep from each treatment. The cores were subdivided into 5 cm horizons. The root biomass was measured once only in early spring (August). The cores were soaked in 10 vol hydrogen peroxide solution for 1 hour before washing and sieving to extract the root material which was then oven-dried and weighed.

Bulk density and total porosity were measured using 5 cm aluminium cores (Gradwell & Birrell 1979). The infiltration rate in the late summer was measured using a 10 cm diameter single ring, one ring on each replicate. Density and soil volumetric water content were measured in soil cores taken from beneath the infiltration rings immediately after the addition of water and a control set of cores for soil moisture determination was taken from areas not receiving artificial watering.

Destructive sampling was kept to a minimum even in the larger plots and there was no direct measurement of the earthworm population. An indirect assessment of earthworm activity was made by counting the worm casts visible on the pasture surface in May and September using 10 × 10 cm quadrats.

RESULTS

The pasture dry matter yields recorded in Trial 1 are shown in Table 1. There was a response in pasture production to the addition of lime on all five dates and an additional small significant response to the presence of earthworms in October and

TABLE 1. Pasture dry matter on Trial 1 at Porongahau

	Mean pasture dry matter production (kg ha^{-1} day^{-1} ± SD)		
	A. longa + lime	Lime	Control
Oct 81	66·7 ± 6·5*	59·3 ± 4·5	23·0 ± 17·1
Nov 81	38·3 ± 3·7*	33·1 ± 4·1	25·2 ± 6·1
April 82	20·1 ± 6·2	29·6 ± 8·9	9·5 ± 8·3
Sept 82	39·4 ± 6·5	37·3 ± 7·2	20·9 ± 14·2
Oct 82	29·3 ± 5·1*	23·1 ± 2·4	16·3 ± 13·2

* Significantly greater than lime-only treatment, $P<0·05$.

TABLE 2. The mean biomass and percentage of roots in each of four horizons in Trial 2 (mg roots per core 10 cm^2 surface area)

	Mean root biomass (mg/core ± SD and %)			
	A. longa		Control	
Soil depth (cm)	Biomass (mg/core)	%	Biomass (mg/core)	%
0–5	814·5 ± 205·4	86·2	1278·6 ± 958·7	91·4
5–10	43·1 ± 18·7	4·4	57·2 ± 42·0	4·1
10–15	31·2 ± 11·3	3·3	33·5 ± 19·7	2·4
15–20	56·2 ± 22·0*	5·0	29·3 ± 12·7	2·1

* Significantly different $P < 0{\cdot}01$.

November 1981, which disappeared in April and September of 1982 but recurred in October 1982.

The biomass of roots in the two treatments of Trial 2 is shown in Table 2. The general distribution of roots was similar in both treatments with the majority of roots in the top 5 cm of the soil profile. The variability in the 0–5 cm horizon was very large and there was no significant difference between the treatments in this horizon. However, at the lowest level sampled (15–20 cm) there was significantly more root biomass ($P < 0{\cdot}01$) on the *A. longa* plots.

The effect of *A. longa* on the total porosity of the soil in Trial 2 is shown in Fig. 1. The upper 10 cm of the profile showed no significant differences but below 10 cm the *A. longa* treatment increased the total porosity ($P < 0{\cdot}05$). The effect of *A. longa* on soil volumetric water content at the end of summer (March) in areas receiving no additional water and in infiltrated areas is shown in Table 3. The percentage moisture was low at this time of year but it was still significantly greater ($P < 0.05$) on the *A. longa* treatment down to 15 cm. The amount of water flowing into the soil from infiltration rings in 25 minutes is shown in Fig. 2. The *A. longa* plots were able to accept almost twice as much water as the untreated plots.

The number of worm casts on the pasture surface of Trial 1 is shown in Table 4. There were more casts in the *A. longa* plots than on the other two treatments,

TABLE 3. The natural volumetric water content of the profile and the volumetric water content of the profile under infiltration rings in soil with and without *A. longa* in March

	Mean volumetric water content ± SD			
	Infiltrated area		Natural area	
Soil depth (cm)	*A. longa*	Control	*A. longa*	Control
0–5	47·2 ± 1·9*	48·0 ± 5·3	23·7 ± 3·8*	18·8 ± 2·8
5–10	45·6 ± 3·1	40·8 ± 8·7	20·2 ± 3·1*	15·8 ± 2·1
10–15	43·8 ± 5·0*	37·5 ± 5·1	18·2 ± 3·1*	14·7 ± 1·4
15–20	40·4 ± 5·0*	35·4 ± 4·9	16·5 ± 4·4	14·6 ± 1·3

* Significantly different $P < 0{\cdot}10$.

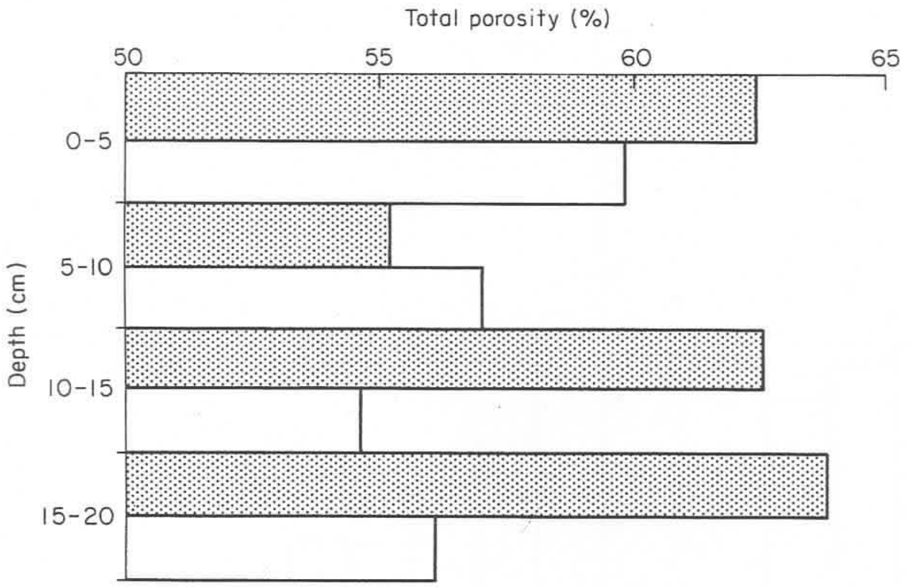

FIG. 1. The total porosity of the soil profile in Trial 2 with *A. longa* (stippled bars) and with resident worms only (open bars).

TABLE 4. The mean number of worm casts (m^{-2}) on Trial 1

	Mean number of worm casts (m^2 ± SD)		
	A. longa + lime	Lime	Control
May 82	310* ± 76·3	228 ± 47·4	152 ± 91·0
Sept 82	297† ± 94·0	181 ± 56·5	151 ± 85·7

Significantly greater than lime-only treatment: * $P < 0{\cdot}05$; † $P < 0{\cdot}01$.

TABLE 5. The mean pH of the soil profile at 2 cm intervals to a depth of 20 cm

	Mean pH			
Depth (cm)	*A. longa* + lime	Lime	Control	LSD (1%)
0–2	6·60	6·60	5·75	0·29
2–4	6·55	6·10	5·50	0·35
4–6	6·30	6·05	5·40	0·37
6–8	5·65	5·90	5·40	0·23
8–10	5·60	5·60	5·40	0·19
10–12	5·60	5·45	5·40	0·16
12–14	5·60	5·45	5·40	0·11
14–16	5·70	5·45	5·20	0·13
16–18	5·75	5·40	5·30	0·12
18–20	5·80	5·40	5·30	0·17

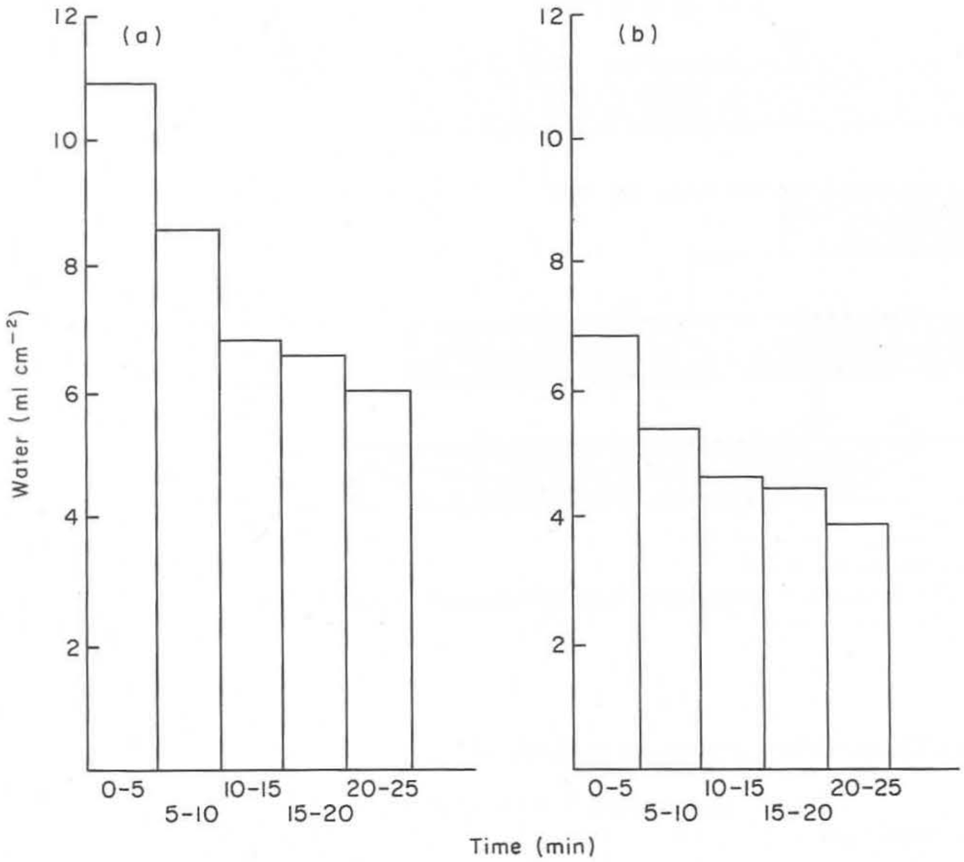

FIG. 2. The acceptance of water in infiltration rings in Trial 2: (a) *A. longa* treatment; (b) control.

although the addition of lime had also stimulated the production of casts by the resident species (*A. caliginosa*, *A. trapezoides* and *L. rubellus*). Liming increased soil pH below 10 cm only in the presence of *A. longa* (Table 5), indicating that in the presence of *A. longa* material is carried from the surface to 15–20 cm depth.

DISCUSSION

The addition of one extra earthworm species (*A. longa*) to the existing population in this New Zealand pasture soil resulted in some measurable changes in the soil structure. Soil porosity in the lower part of the profile was increased and it is suggested that it was these changes in soil structure which allowed greater root development in the 15–20 cm soil horizon. These changes occurred within 18 months of introduction. It has been shown (Kretzschmar 1983; Springett 1983) that *A. longa* transports soil vertically, taking material from the surface and depositing it at depth, and vice versa. The present work shows that when *A. longa*

are active, a greater number of earthworm casts is deposited at the surface. That this also modifies the soil structure below 10 cm, and the distribution of plant roots, has been shown in the present field study and in the laboratory (Edwards & Lofty 1979).

In New Zealand pasture soils, where the earthworm fauna is dominated by the superficially active species *A. caliginosa* and *L. rubellus*, it may be important for the long-term fertility of pastures to ensure that the earthworm fauna contains a range of species occupying different ecological niches. Lavelle (1983) states that temperate grasslands have mainly (72%) anecic species. However, the category 'anecique' as described by Bouché (1977) includes *A. longa* but not *A. caliginosa*, which falls in to the 'endogées', so that most New Zealand pastures do not conform to the pattern described by Lavelle (1983). When *A. longa* is introduced, changes in soil structure occur which are sufficient to influence the growth of both roots and above-ground vegetation; suggesting that the productivity of New Zealand exotic grasslands is increased by an anecic earthworm fauna. If our aim is to understand the root environment and to manage it to improve production then detailed information on the way in which each species alters the water-holding capacity, the aeration and the nutrient availability in the root environment will be required.

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